

SUSTAINING SOIL PRODUCTIVITY OF COTTON-BASED CROPPING SYSTEMS IN THE SAVANNAHS OF WEST AND CENTRAL AFRICA: CHALLENGES AND OPPORTUNITIES

P. Titttonell and M. Cretenet

Systèmes de Culture Annuels, CIRAD-Persyst, Montpellier, France

ABSTRACT

The production of cotton (*Gossypium* spp.) is one of the major economic activities in many countries of West and Central Africa. Traditionally, cotton production was seen as ‘engine for development’ in rural Africa, but deregulation and the dismantling of commodity boards, and severe fluctuations in international fibre prices led to a considerable decrease in the areas under cotton in the region and declining cotton yields. Food crops such as maize or sorghum are increasingly replacing cotton on the land cultivated by smallholders. This poses an important threat to the maintenance of soil productivity, since cotton is often the sole entry point of nutrients to the cropping system when fertilisers are provided by the industry. The consequences of this are examined through analysis of existing agronomic and experimental evidence from cotton-based agroecosystems in the region, and ways forward for agricultural research for development are outlined.

INTRODUCTION

The production of cotton is one of the major economic activities in many countries of West and Central Africa, representing up to 75% of the value of agricultural exports of countries, such as Cote d'Ivoire, Benin, Burkina Faso and Mali (OCDE, 2006). Traditionally, cotton production was seen as ‘engine for development’ in rural Africa – “*Cotton builds roads, cotton brings water, cotton opens schools...*”.



Figure 1: Overview of the agricultural landscape at Mafa Kilda, near Garoua, in the *savanes cotonnières* of northern Cameroon

Deregulation of production and marketing and the dismantling of national commodity boards, in combination with severe fluctuations in the international price of fibres have led to a considerable decrease in the areas under cotton in the region, and to important losses in average cotton yields (ICAC, 2008). The areas that continued being cultivated to cotton received decreasing nutrient inputs, leading to severe soil fertility and productivity decline (Cretenet et al., 2007). Food crops such as maize or sorghum, which may fetch more attractive prices on the market, are increasingly replacing cotton on the land cultivated by smallholders (ICAC, 2008). These crops produce a stover that is also much appreciated for animal feeding. Under the current scenario of ever increasing food

prices, the reduction in the areas cropped to cotton is likely to be exacerbated. This poses an important threat to the maintenance of soil productivity, since cotton is often the sole entry point of nutrients to the cropping system when fertilisers are provided by the industry. Fertiliser use in cotton allows subsequent crops to benefit from residual fertility in a rotation. When combined with the shifting of crops in space, this residual fertility may allow sustaining food production. The practice of fallow or the use of animal manures, traditional ways of maintaining soil fertility, are less and less feasible in the face of rural population growth and increasing ratios of cropland-to-grassland (de Ridder et al., 2004). This contributes to biodiversity loss and to more rapid soil fertility decline. Poor soil fertility leads to poor crop growth and thus more soil is exposed to heavy rains, leading to soil losses by erosion. Investments in maintaining soil productivity in the region are also hampered by increasing risks associated with climate change, notably with a shortening of the rainy season. Farmers' perception of such changes makes them less eager to invest their limited resources, a situation that is not buffered by any policy or insurance mechanism. In risky environments, credits may be out of question as policy instruments to boost agricultural production, since farmers are often not takers. The combined effect of these processes is illustrated with a case study from the northern savannahs of Cameroon, where changes in policy and relative prices have led to irregular additions of nutrient sources to replenish soil fertility, and the consequences are difficult to revert. Further evidence on long term soil productivity as affected by the amount and type of nutrient inputs to the soil is presented for cotton based-systems of Mali.

NORTH CAMEROON: A CASE OF DECREASING PRODUCTIVITY AND SOIL FERTILITY DECLINE

In the *savanes cotonnières* of northern Cameroon, average yields and the average rates of fertiliser use on cotton have declined over the last 25 years, as confirmed by a longitudinal survey conducted in the major cotton production area of Garoua (Figure 2). Until the early 1980s, farmers applied on average of 220 ± 5 kg ha⁻¹ of NPK compound fertiliser. As from 1986, discontinuation of governmental policies for the sector led to a decline in fertilizer rates down to 150 ± 7 kg ha⁻¹. New promotional policies from 1997 help increasing this average to 165 ± 20 kg ha⁻¹, with larger variability in the application rates adopted by farmers. However, yields did not improve with respect to the previous period, and yields without fertilisers decreased dramatically.

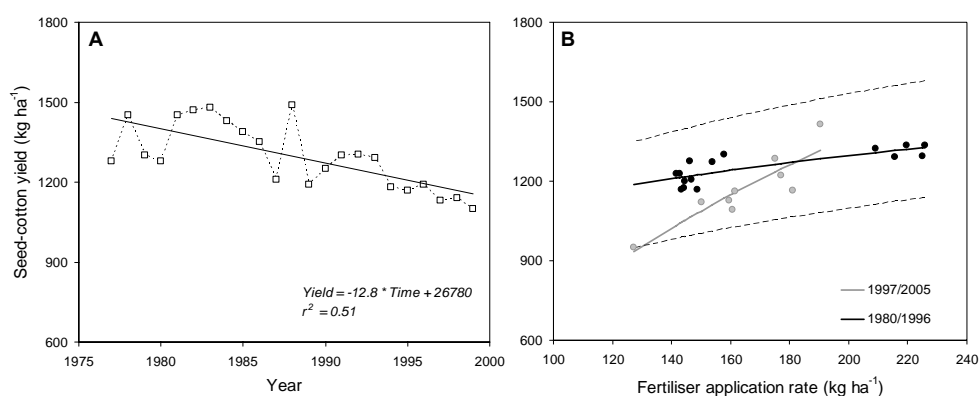


Figure 2: Changes in productivity and in crop responses to mineral fertilizers in Cameroon; (A) Evolution of average seed-cotton yields at national level; (B) Average seed-cotton yields and fertilizer application rates on farmer fields at Garoua, N Cameroon, during 1980-1996 and 1997-2005. Dotted lines correspond to linear trends fitted to the upper and lower quintiles of the samples 1980-1996.

To unravel the effects of changes in soil fertility, or the capacity of soil nutrients to sustain crop growth, and in soil productivity, the capacity of the soil to ensure crop responses to applied nutrients in these cotton-based agroecosystems we performed a meta-analysis of yield-response data from Garoua, which consisted of 188 farmer-managed plots of cotton receiving from 0 to 500 kg ha⁻¹ of NPK fertiliser. We used a Mitscherlitch function [$yield = a + b*(1 - e^{-cF})$, with $F = \text{kg ha}^{-1}$ of fertiliser] and interpreted its parameters as follows: the intercept a represented the intrinsic soil fertility (without fertilisers); the slope b the rate of response to applied fertilisers; and the asymptote $a + b$ the production potential (soil productivity with fertilisers). We studied the variation in these parameters with respect to changes in soil quality indicators (organic C, available P, exchangeable bases) over the period considered. For the period 1980-1996, the model that best described the average yield response to fertilisers had parameter values of $a = 1004 \text{ kg ha}^{-1}$ and $a + b = 2051 \text{ kg ha}^{-1}$. Absolute responses to maximum fertilisers rates varied from 845 and 770 kg ha⁻¹ in 'poor' and 'fertile' fields, respectively, to 1045 kg ha⁻¹ in fields of intermediate fertility. Both soil fertility (a) and soil productivity ($a + b$) decreased gradually over time, reaching values of $a = 598 \text{ kg ha}^{-1}$ and $a + b = 1651 \text{ kg ha}^{-1}$ in the season 2005-2006. Soil organic carbon and the cation exchange capacity were the soil fertility indicators that correlated best with the variability in the values of a and b . These results suggest that once a certain lower threshold of soil organic matter is trespassed, soil degradation becomes hard to revert through fertiliser use, and more drastic measures (such as changing cropping sequences, or even land use) may be necessary. Knowing these thresholds for the range of soil and climatic conditions of the West Africa cotton belt may allow better targeting of agricultural development, agronomic and even policy interventions.

LONG TERM EXPERIMENTS AT N'TARLA, MALI: CAN SOIL FERTILITY BE MAINTAINED WITH ORGANIC VS. MINERAL FERTILISERS APPLIED ON COTTON?

Long term experiments offer a unique opportunity to assess sustainability and temporal dynamics of biogeochemical cycles in agriculture, as well as the gradual impact on these of relatively slow processes such as climate change. Soil carbon thresholds referred above may be investigated through the results of long-term trials. A long term experiment on cotton-based crop rotations representing locally common cropping systems and cultural practices was established in Mali in 1965. This experiment was designed to assess the long-term productivity of these systems under different organic matter and nutrient management regimes, applying organic and mineral soil amendments alone or in combination. The experiment was conducted during 24 years in a zone of mono-modal rainfall (c. 900 mm year⁻¹) on an Alfisols soil type (5% clay), and consisted of quadrennial/triennial rotations of cotton (2x), sorghum and groundnuts. Organic matter was added as straw collected from adjacent fallow fields at a rate of 15 t ha⁻¹ every three years, with and without application of N-P-K mineral fertilisers at an average rate of 30, 20 and 40 kg ha⁻¹ year⁻¹, respectively (Kone, 1989). Crop residues were incorporated in the soil every year.

Over 24 years, seed-cotton yields were larger than the control on plots receiving organic and/or mineral soil amendments (Figure 2 A), and yields were comparable when organic fertilisers (animal manure) were applied either with or without mineral fertilisers. Soil organic C declined in control plots and in those receiving only mineral

fertilisers (Figure 2 B). Addition of $15 \text{ t ha}^{-1} \text{ year}^{-1}$ of organic matter allowed maintaining soil C contents at original levels, while its combination with mineral fertilisers had only a marginal effect on increasing soil C contents further. Addition of mineral fertilisers alone allowed sustaining crop productivity over the first 10 years, but yield tended to decline with respect to manured treatments afterwards. Such a decline led also to a decline in soil organic carbon under sole fertiliser.

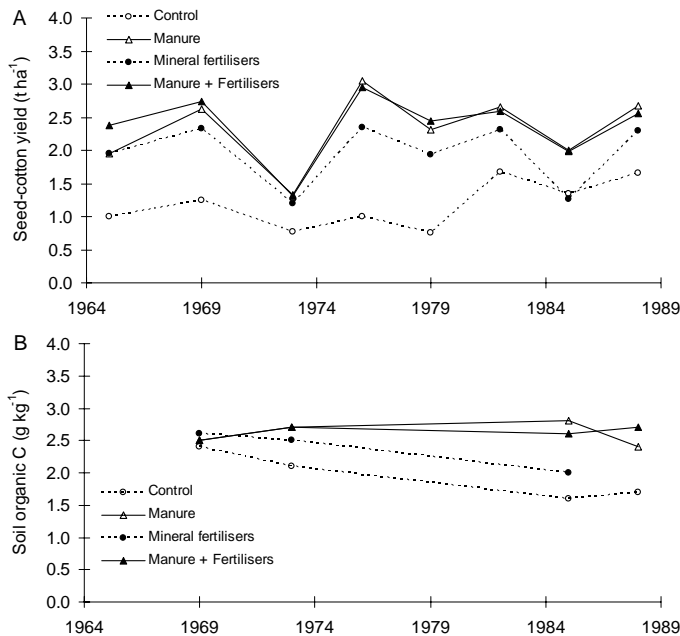


Figure 1: Evolution of seed-cotton yields and soil organic C content under different soil fertility management as measured in long-term experiments at N'Tarla (Mali) over 24 years.

Plausible scenarios of climate change envisaged for West Africa include greater rainfall variability (a delay in the offset and a shortening in the length of the cropping season) and increased air temperatures. These effects can be already seen in the data collected during this experiment (Figure 3).

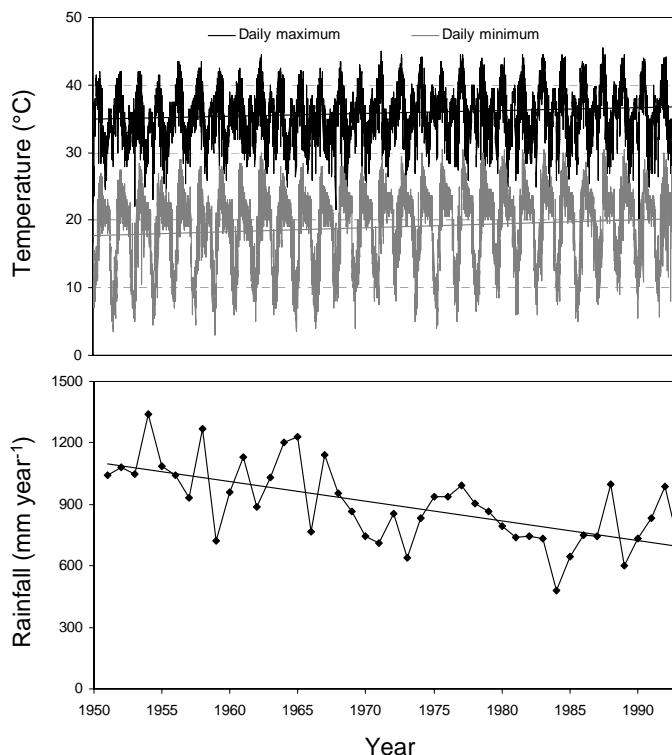


Figure 3: Daily maximum and minimum temperatures and annual rainfall recorded over 24 years at the experimental station of N'Tarla, Mali.

Less rainfall and higher temperatures translate into further less inputs of C to the soil due to poorer crop productivity, and in faster mineralisation rates of soil organic matter due to higher soil temperatures, leading to undesirable positive feedbacks (less C inputs and more rapidly decomposed soil C). Since fast mineralisation rates under tropical conditions do not allow substantial increases in organic C contents in soils receiving regular organic matter inputs, measures to reduce mineralisation (e.g., no or minimum tillage, mulching) may propend to agricultural sustainability in the region.

THE WAY FORWARD

The examples presented indicate that soil productivity in cotton based systems of the West and Central African savannahs cannot be maintained solely with mineral fertilizer inputs, unless parallel measures are taken to ensure (i) enough regular C inputs to the soil via crop residues of certain quality, and (ii) that the C thus added to the soil and that already present in it are not lost through accelerated decomposition. Measures that propend to fulfilling these two conditions contribute also to increase soil water infiltration and storage capacity, thereby reducing the impact of climatic risks, and to sequester atmospheric CO₂ in the soil organic compartment, providing environmental services of global interest – and potentially tradable. However, achieving this implies removing/ reducing the impact of various constraints to cotton-based systems in the region; an important one being the pressure of insect pests that affect plant growth and fiber quality. This leads to heavy use of pesticides, with their associated risks for the environment and human health and their impact on production costs. To overcome this problem – albeit partially – some countries in the region allowed the introduction/testing of genetically modified (Bt) cotton varieties. While the environmental consequences of this are still unknown, its effectiveness is questionable. And besides, would the international community be willing to pay for carbon that is sequestered under agricultural models that rely on genetically modified organisms?

The French International Agricultural Research for Development Centre (CIRAD) has a long history of collaboration with national research institutes, universities and cotton industry boards in West and Central Africa. Such partnership has allowed much progress on agricultural research that seeks technical-economical solutions to cotton production, including (i) improved cotton varieties with resistance to biotic and abiotic stresses, (ii) integrated soil fertility management and soil conservation measures, (iii) integrated pest management, (iv) whole-chain approaches that assure fiber quality, and (v) socio-economic research that supports innovation and efficiency throughout the production chain. Currently, CIRAD develops a project aiming at designing multifunctional cotton-based agroecosystems for the West and Central African savannahs, able to provide incomes, food and environmental services. Such efforts have an impact, and yet there is a long way to go in many areas of research. But research cannot change the region's socio-political context or the international 'laws' of trade. Worldwide efforts that include changes in consumption patterns, and in the commercial balances between producers, manufacturers and dealers are also necessary.

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